Research Brief for
DOE/IHEA Process Heating Materials Forum

Research Title: Materials Degradation Processes in Elevated-Temperature Environments Relevant to Process Heating

Industry Need: Materials degradation controlled by high-temperature corrosion and environmental effects comprises a key life-limiting set of phenomena for the process heating community. This is manifested in the needs for (1) longer-lived heating devices (elements, radiant tubes, etc.), (2) improved refractories and insulation for combustion chambers and furnace walls, (3) materials for recuperators and other types of heat exchangers as well as high-temperature fans, (4) weight reduction for furnace hardware through enhanced corrosion résistance (reduced starting section thickness), and (5) extended protection of sensors.

Existing Research: At Oak Ridge National Laboratory (ORNL), a number of research projects are devoted to the study of the mechanisms of high-temperature materials degradation (in gaseous, salt, and liquid metal environments) and related development of alloys, ceramics, and coatings. This summary will primarily address research related to materials behavior in gases as much of the current high-temperature corrosion work involves such environments. However, ORNL has longstanding research experience in corrosion by molten salts (fluorides, nitrates, sulfides, sulfates) and liquid metals (lithium, lead, mercury, aluminum, zinc) and there are several active projects in these areas.

At present, ORNL has a substantial program involving the development of creep- and oxidation-resistant alloy foils for use in recuperators for power generation and other thin-wall applications at high temperature. Laboratory experiments in high-temperature air plus water vapor (to simulate combustion environments) are coupled with characterization of field-exposed recuperators and creep testing to understand the life-limiting processes occurring at high temperatures in relevant environments and thus to contribute to improvements in materials performance by alloy selection and optimization. The work is conducted in collaboration with alloy suppliers and recuperator manufacturers/users to assure that research results are then translated into practice and application. A similar approach (lab experiments and associated field evaluation, collaboration with industry) is used with

- ceramic composites and coatings for combustion applications
- metallic filters for clean up of coal-derived fuel gas, and
- refractories for kraft recovery boilers and black liquor gasification.

ORNL has several other research projects aimed toward the understanding of how protective chromia and alumina layers form and remain stable and adherent on alloys exposed to high-temperature oxidizing, sulfidizing, and carburizing environments. These studies support objectives related to the development of advanced alloys and coatings for use in high-temperature energy systems (such as coal gasification, advanced steam cycles, and higher efficiency land-based gas turbines) and industrial processes (for example, ethylene cracking) to reduce section thickness, enhance performance, and/or extend materials lifetime. There also is work on the development of materials for thermocouple protection in high-temperature gaseous and salt (slag, smelt) environments and the use of high-temperature nitridation to form functional surfaces on appropriate alloys. In support of most of these projects, there are ongoing efforts to develop models and methodologies for oxidation- (corrosion-) limited lifetime prediction at high temperature. Many specialized high-temperature exposure facilities and processing methods are utilized. These are combined with thermodynamic and kinetic modeling capabilities and a range of traditional and advanced microstructural and microchemical characterization techniques to develop the appropriate structure-composition-properties-corrosion behavior relationships needed for materials selection and development and performance prediction.

Proposed Activity: Based on existing research in high-temperature materials degradation and associated development, there are activities that could support the needs of the process heating industry in a number of the areas listed above by building on the techniques and expertise currently being used and evolved. In particular, the behavior of several of the relevant types of materials presently being investigated (high-strength foils, standard and advanced alloys and coatings, ceramic composites) could be studied in appropriate process-heating gases (nitriding, carburizing, and combustion) to examine the effectiveness of approaches based on development of protective (stable, sound, adherent) surface reaction layers in other high-temperature environments and to identify lifetime modeling issues and methodologies under these conditions. The work would involve laboratory-based efforts as well as characterization of field-exposed materials as appropriate.

Lead Scientist: P.F. Tortorelli, Distinguished Staff Member and Leader, Corrosion Science and Technology Group, Metals and Ceramics Division, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, Tennessee 37831-6156; (865) 574-5119, (865) 241-0215 (FAX), tortorellipf@ornl.gov